LABORATORY FOR

ATMOSPHERES

Section 5

5. 1996 Highlights

Laboratory scientists have contributed directly to the advancement of Earth and space science by publishing 176 articles in refereed journals during the past year (listed in Section 7), as well as presenting talks and written articles for public and professional audiences. Other publications by Laboratory scientists include NASA Technical Memoranda, technical books and book chapters, and expositions related to national and international scientific policy issues (listed in Section 8). While it is not possible to mention all of these accomplishments in this report, a few examples illustrate the breadth and quality of Laboratory achievements. These examples correspond to work completed or nearly completed during 1996. The selection was somewhat subjective and time will tell the ultimate impact that these contributions will have.

All the highlights listed below are the achievements not only of civil servants and non-civil servants who work in the Laboratory, but also of many other colleagues at Goddard, at NASA Headquarters, at other NASA centers (Ames, Langley, Jet Propulsion Laboratory (JPL), and Marshall, in particular), at private companies, and at other government laboratories and universities in the United States and abroad.

(Return to Table of Contents)

5.1 Measurements and Data Products

Planetary Atmospheres

- Cassini Mission to Saturn

The Atmospheric Experiment Branch delivered two instruments which are part of the Cassini Mission to Saturn: the INMS for the Orbiter and the GCMS for the Huygens Probe. The Cassini Mission to Saturn is a joint effort between NASA and the European Space Agency (ESA). The Saturn Orbiter is under development by NASA; the Huygens Probe will investigate the atmosphere of Titan and is under development by ESA.

The GCMS is a very versatile gas chemical analyzer designed to identify and quantify the abundances of various constituents in the atmosphere of Titan, including argon, other noble gases, and isotopes. Its Qualification Model (QM) and Flight Model (FM) were delivered to Daimler-Benz Aerospace in Germany for integration on the Huygens Probe.

The INMS is intended to measure positive ion and neutral species composition and structure in the upper atmosphere of Titan and the ion and neutral environments of Saturn's icy satellites, rings and magnetosphere. The INMS Engineering Model was delivered to the JPL for integration on the Saturn Orbiter.

Launch of the Cassini Spacecraft is scheduled for October 1997 with Saturn encounter in 2004.

Data Assimilation Studies

- GEOS-2 Data Assimilation System (DAS)

Validation tests show that the GEOS-2 DAS provides a significant improvement over GEOS-1 DAS. GEOS-2 DAS is the baseline version of the GEOS DAS system which will become the operational system in support of the EOS AM-1 platform. GEOS-2 DAS is being used to provide support for ADEOS, with a particular focus on marine surface winds from NASA Scatterometer (NSCAT) observations. It will be used to develop precipitation assimilation capabilities from TRMM data.

Characteristics of GEOS-2 DAS which represent advances over GEOS-1 DAS include increasing the vertical resolution to 70 levels, with special attention to the planetary boundary layer and the stratosphere. GEOS-2 DAS is the first implementation of the Physical-space Statistical Analysis System which is the first analysis system that allows completely general representation of error characteristics [1]. The Physical-space Statistical Analysis System also provides the framework to incorporate new data types which will be available from MTPE platforms. The GEOS-2 DAS system is described in the DAO Algorithm Theoretical Basis Document which is available from the DAO at http://dao.gsfc.nasa.gov/subpages/atbd.html.

1. "Assessing the Effects of Data Selection with the DAO Physical-Space Statistical Analysis System," A. M. da Silva, J. Guo, S. E. Cohn, J. Pfaendtner, M. Sienkiewicz, and D. Lamich, to be submitted to *Mon. Wea. Rev.*, 1997.

- Kalman Filter Data Assimilation of Halogen Occulation Experiment (HALOE) Constituent Observations

The DAO has implemented the first global atmospheric Kalman filter data assimilation system [1]. The first implementation was on the INTEL Paragon at JPL and the system is now running on the Cray T3-D at Goddard. The Kalman filter has been used to assimilate methane data from HALOE, an occultation instrument aboard UARS. Even though HALOE provides less than 30 profiles per day, the Kalman filter generates global maps which validate well with the more dense measurements of other instruments on the UARS platform [2]. The success of the HALOE assimilation has motivated further research into using SAGE data with the goal of developing long-term data sets with improved representation of lower stratospheric ozone. These data sets will be used with TOMS data to provide improved estimates of tropospheric ozone.

1. "Parallel Implementation of a Kalman Filter for a Constituent Data Assimilation," P. M. Lyster, S. E. Cohn, R. Menard, L.-P. Chang, S.-J. Lin, and R. G., in press *Mon. Wea. Rev.*, 1996.

2. "Assimilation of Constituent Observations in the Stratosphere," R. Menard, L.-P. Chang, P. M. Lyster, and S. E. Cohn, to be submitted to *J. Geophys. Res.*, 1997.

- Consistent Assimilation of Retrieved Data

The DAO has developed a new methodology which allows assimilation of retrieved data while maintaining the fidelity of error representation thought possible only through the direct use of radiances [1]. The methodology is called the Consistent Assimilation of Retrieved Data (CARD). CARD and associated data reduction algorithms provide an important and necessary advance because of the large data volumes associated with MTPE observations. Instead of having to move and assimilate hundreds of gigabytes of radiance data, the information content can be compressed into files two or more orders of magnitude smaller at the data archive. CARD is a important theoretical advance with tremendous operational consequences.

1. "Efficient Methods to Assimilate Satellite Retrievals Based on Information Content," J. Joiner and A. M. da Silva, submitted to *Q. J. Roy. Meteor. Soc.*, 1996.

Data Sets for Climate Analysis

- Sea Surface Wind Data Set

A multiyear (1987-1995) data set from SSM/I marine surface wind speed observations has been developed and archived at the JPL Distributed Active Archive Center (DAAC) [1]. This data set uses assimilation methods to assign wind direction information to the SSM/I wind speeds and also fills in unobserved regions between satellite swaths. The data have been successfully used to drive ocean circulation models, and have revealed previously unobserved interannual variability of large scale convergence centers [2]. The SSM/I data have been used as a prototype to develop assimilation and analysis techniques to utilize scatterometry observations from NSCAT aboard the ADEOS satellite launched in Summer 1996. The data are currently being used with the GEOS DAS at Goddard in NSCAT validation activities.

1. "A Multiyear Global Surface Wind Velocity Dataset Using SSM/I Wind Observations," R. Atlas, R. N. Hoffman, S. C. Bloom, J. C. Jusem, and J. Ardizzone, *Bull. Amer. Meteor. Soc.*, **77**, 869-882, 1996.

2. A Comparison of Surface Wind Products over the North Pacific Ocean," M. M. Rienecker, R. Atlas, S. D. Schubert, and C. A. Scholz, *J. Geophys. Res.-Oceans*, **101**, 1011-1023, 1995.

Aerosols

- Aerosols Effects on Climate

First measurements were reported of the efficiency of tropospheric aerosol particles to reflect radiation back to space, and thus cool the Earth [1]. Aerosol particles from anthropogenic or natural sources generate a negative radiative forcing of the climate system, by directly reflecting sunlight back to space, and positive forcing by absorbing solar radiation. The efficiency □ of backscattering of incoming radiation by aerosol particles was previously calculated from models of aerosol physical properties or derived from ground based aerosol volumetric measurements. Systematic sky spectral radiance measurements were used to derive the value of □ for smoke aerosol in Brazil and for industrial/urban aerosol in the Mid-Atlantic region of the United States. Since aerosol particles scatter light upward to space and downward towards the Earth, the sky radiance can be used to derive the fraction of solar flux reflected to space. The aerosol measurements are of the ambient aerosol and are integrated on the vertical column.

The average value of □ derived from the measurements varied between 0.20 and 0.28 for both aerosol types, as compared to 0.29 used by other authors [2, 3] in their modeling efforts to calculate radiative forcing by sulfate and smoke aerosol, respectively. They used the average value of □ on all solar illumination directions. But high optical thicknesses occur in the Amazon and Eastern United States during the period of July to September, when the solar elevation is high. For these months and latitude range the actual average value of □ is 25% lower for the same two aerosol types. A combination of these two factors results in values of □, and the corresponding aerosol direct radiative forcing of climate, that are 30-50% lower than the previous estimates.

1. "Hemispherical Backscattering by Biomass Burning And Sulfate Particles Derived from Sky Measurements," Y. J. Kaufman and B. N. Holben, *JGR-Atmospheres*, **101**, 19433-19445, 1996.

2. "Climate Forcing by Anthropogenic Aerosol," R. J. Charlson, S. E. Schwartz, J. M. Hales, R. D. Cess, J. A. Coakley, Jr., J. E. Hansen, and D. J. Hoffman, *Science*, **255**, 423-430, 1992.

3. "Effects of Aerosol from Biomass Burning on the Global Radiation Budget," J. E. Penner, R. E. Dickinson, and C. A. O'Neill, *Science*, **256**, 1432-1434, 1992.

Ozone and Trace Gas Measurements

- New TOMS Satellites Successfully Launched

In July and August 1996, successful launches put new TOMS instruments into orbit, ending the 2-year hiatus following a 16-year data record. Global ozone had been monitored for 16 years by TOMS instruments on Nimbus 7 (11/78-5/93) and on Meteor 3 (8/91-12/94). Earth-Probe TOMS, launched on 2 July on a Pegasus vehicle, was placed into a 500 km orbit for 25 km ground resolution, which aids in the retrieval of lower tropospheric ozone, dust and aerosols. The Japanese ADEOS TOMS was launched on 17 August in an 800 km orbit and provides a 42 km ground resolution. Near-real-time TOMS data from Earth Probe and ADEOS are being distributed via the internet (at: http://jwocky.gsfc.nasa.gov/).

The Flight Projects Directorate, Code 400, at Goddard oversaw the construction of the TOMS instruments and the Earth Probe (EP) spacecraft. The Atmospheric Chemistry and Dynamics Branch scientists contributed to the original scientific motivation for the missions and are the Project and Instrument Scientists.

- Version 7/TOMS Data: A 16-Year Record of Ozone

New self-consistency techniques for calibrating in- orbit instruments have achieved an unprecedented accuracy of 1% over 16 years in the version 7 TOMS data [1, 2] released to the public in April 1996. CD-ROMs of TOMS data (5000 copies) were produced and are being distributed worldwide through the Goddard DAAC. This high accuracy allowed the development of unanticipated new TOMS products such as ground level UV [3] and absorbing aerosols.

The TOMS ozone maps have led to world-wide recognition of the Antarctic "ozone hole" and were critical in developing the understanding of its formation. TOMS data have had a significant influence on international treaties on CFC control.

1. "An Assessment of the Accuracy of 14.5 Years of Nimbus 7 TOMS Version 7 Ozone Data by Comparison with the Dobson Network," R. D. McPeters and G. J. Labow, *Geophys. Res. Lett.*, **23**, 3695-3698, 1996.

2. "Long-Term Trends Derived from the 16-Year Combined Nimbus 7/Meteor 3 TOMS Version 7 Record," R. D. McPeters, S. M Hollandsworth, L. E. Flynn, and J. R. Herman, *Geophys. Res. Lett.*, **23**, 3699-3702, 1996.

3. "UV-B Increases 1979-1992 from Decreases in Total Ozone," J. R. Herman, P. K. Bhartia, J. Ziemke, Z. Ahmad, and D. Larko, *Geophys. Res. Lett.*, **23**, 2117-2120, 1996.

- Stratospheric Transport of Atmospheric Tracers (STRAT)

The STRAT series of ER-2 flights out of NASA Ames and Hawaii made two breakthroughs in 1996. First, by flying in a stacked flight path--something only recently allowed by flight operations, STRAT obtained an unprecedented high-resolution cross-section of trace gas constituents of the upper troposphere/lower stratosphere. Lifetimes of tracers in the "middle world" where potential temperature isopleths enter the upper tropical troposphere have been determined [1]. Mean lifetimes for stratospheric air vary from 1-5 years, which is analogous to exhaust lifetimes from proposed high-altitude stratospheric aircraft. Second, OH measurements on STRAT were the first to be made in the upper troposphere. OH is the key atmospheric oxidant that controls the buildup of greenhouse gases like methane and substituted chlorofluorocarbons.

The STRAT mission was a NASA sponsored mission involving several NASA centers, other government laboratories, and universities. Scientists from the Laboratory for Atmospheres contributed to the conception and planning of the mission, and provided meteorological support, including generation of forecasts and analysis using the GEOS DAS. The mission Co-Project scientist was a member of the Atmospheric Chemistry and Dynamics Branch.

1. "Stratospheric Mean Ages and Transport Rates from Observations of Carbon-Dioxide and Nitrous-Oxide," K. A. Boering, S. C. Wofsy, B. C. Daube, H. R. Schneider, M. Loewenstein, and J. R. Podolske, *Science*, **274**, 1340-1343, 1996.

Remote Sensing of Clouds and Water Vapor

- Inference of Marine Atmospheric Boundary Layer Water Vapor and Temperature Profiles using Airborne Lidar and Radiometer Data

Data gathered during an extended airborne field campaign over the Atlantic Ocean in support of the Lidar In-space Technology Experiment (LITE) has been used to develop a new technique for the retrieval of moisture and temperature profiles throughout the Marine Atmospheric Boundary Layer (MABL). The technique utilizes lidar derived statistics on the height of cumulus clouds which frequently cap the MABL to estimate the Lifting Condensation Level (LCL). Combining this information with radiometer derived SST measurements, an estimate of the near surface moisture can be obtained to an accuracy of about 0.8 grams of water vapor per kg of dry air.

Lidar derived statistics on convective plume height and coverage within the MABL are then used to derive the profiles of potential temperature and moisture with a vertical resolution of 20 meters. The retrieved profiles compare favorably with dropsonde measurements and demonstrate consistently good results. The root-mean-square error of average MABL moisture content and potential temperature obtained from 16 retrieved profiles is less than 1 g/kg and 1 degree Celsius, respectively [1]. The method relies on the presence of a cumulus-capped MABL and relatively small air-sea temperature differences such as that found over the tropical and sub-tropical regions. The technique has also been successfully applied to actual LITE data and the results show promise for the retrieval of MABL moisture and temperature over the tropics and sub-tropics using spaceborne lidar. Future work will combine scatterometer-derived wind speed and moisture retrievals near the surface to estimate latent heat flux over the ocean. Additional work will also be done to assess the applicability of the technique over land areas using LITE data.

1. "Airborne Remote Sensing of Atmospheric Boundary Layer Water Vapor and Temperature Profiles over the Ocean," . S. P. Palm, D. Hagan, G. Schwemmer, S. H. Melfi, submitted to *J. Appl. Meteor.*, 1996.

- The ER-2 Doppler Radar (EDOP)

The complex nature of updrafts, downdrafts, and reflectivities on scales of 1 to 2 km has been observed using the EDOP data [1, 2]. The airborne EDOP provided unique high-altitude observations of extensive storm systems during a second Convection and Moisture Experiment (CAMEX-2) which took place during the summer of 1995 and focused in part on the vertical structure of precipitation in convective systems. The data clearly show the complex nature of up and downdraft couplets within individual convective cells with dimensions of only 1 to 2 km. Another remarkable result from the high resolution EDOP observations is the appearance of strong updrafts/ downdrafts near the cloud top. Individual updraft cells such as those observed by the EDOP radar have significantly smaller dimensions than the footprints of spaceborne instruments. In remote or oceanic areas where no ground-based Doppler radar data exists, observations from EDOP can provide information on the highly detailed vertical structure of precipitation and wind-flow fields needed to better understand and validate precipitation retrievals from spaceborne instruments.

EDOP has had significant impact upon the TRMM validation strategies. EDOP observations have been used to simulate TRMM Precipitation Radar (PR) nadir observations to provide guidance in developing PR algorithms as well as validation strategies. These simulations have focused the emphasis upon the differences that one can expect from intercomparison between spaceborne and ground-based radars. Precipitation bright bands clearly visible with 4 km spatial and 250 m vertical resolution commensurate with the PR, for instance, can be completely missing from a ground-based radar less than 100 km away from the precipitation. Such analyses have a profound impact upon the very nature of the validation experiments that must be planned for the TRMM mission, refocusing attention from a philosophy of belief in ground "truth" to one that seeks to understand the underlying physics of the observations.

EDOP was built in collaboration with the Microwave Sensors Branch of the Laboratory for Hydrospheric Processes.

1. "Structure of Florida Thunderstorms Using High-Altitude Aircraft Radiometer and Radar Observations," G. M. Heymsfield, I. J. Caylor, J. M. Shepherd, W. S. Olson, S. W. Bidwell, W. C. Boncyk, and S. Ameen, *J. Appl. Meteor.*, **35**, 1736-1762, 1996.

2. "The EDOP Radar System on the High-Altitude NASA ER-2 Aircraft," G. M. Heymsfield, S. Bidwell, I. J. Caylor, S. Ameen, S. Nicholson, W. Boncyk, L. Miller, D. Vandermark, P. E. Racette, and L. R. Dod, *J. Atmos. Oceanic Tech.*, **13**, 795-809, 1996.

- Investigation of the Effect of Contrail Cirrus on Climate

A NASA remote sensing experiment has provided results which indicate the potential for contrail cirrus as an anthropogenic factor on climate change. Observations of contrail cirrus have been obtained by remote sensing from the NASA ER-2 high altitude aircraft. The observations involve multispectral visible and infrared imagery, high frequency microwave and active lidar sensing. In 1996, the SUCCESS project was specifically directed to the problem of contrail cirrus. Of special importance, remote sensing observations contained contrails verifiable from observations by lower altitude aircraft participating in SUCCESS. There are preliminary conclusions from this and previous experiments [1]. Newly produced contrails are composed of ice crystals with significantly smaller effective size than those found in the ambient cirrus and have significantly different radiative properties. Older contrails suggested microphysics similar to those of the ambient cirrus. Contrail ice/water content retrievals show that contrails are similar in water content to nearby natural cirrus and that jet exhaust vapor is an insignificant component. Estimates from remote sensing data indicate that contrails do not add significantly to cloud radiative forcing effects. But, through their interaction with the ambient cirrus and water, they may increase the radiative forcing of large areas of cloud cover if it can be determined that the contrails influence a large scale perturbation in the cloud fields. In a spectacular experiment on May 15, 1996 the NASA DC-8 aircraft participating in SUCCESS generated an oval shaped contrail cloud that could be seen and tracked in GOES satellite images from off the coast of California through Utah. The completion of studies involving both aircraft and global analysis of satellite data is required to determine the overall climate effect of aircraft generated cirrus.

1. "Contrail Microphysics and Radiative Properties from Aircraft Remote Sensing," C. Drummond and J. D. Spinhirne, submitted to *J. Appl. Meteor.*, 1996.

(Return to Table of Contents)

5.2 Data Analysis

Planetary Atmospheres

- Analysis of the Jovian Atmosphere

The Atmospheric Experiment Branch's contribution to the Galileo mission to Jupiter was the mass spectrometer on the Galileo Probe. Shortly before arrival at Jupiter, the Probe separated from the Galileo Orbiter, entered the atmosphere, and descended on a parachute December 7, 1995, into the deep Jovian atmosphere. Data were collected by the mass spectrometer for 57 minutes, from an atmospheric pressure of approximately 0.3 to 23 times Earth sea level pressure where the Probe data transmission stopped. The Galileo Probe Mass Spectrometer (GPMS) was the primary Probe instrument to measure chemical composition of the atmosphere of Jupiter which consists primarily of hydrogen and helium, with smaller amounts of water, methane, ammonia, hydrogen sulfide, and lower concentrations of other molecules. The Galileo Probe Mass Spectrometer measured variations in the abundance of all these species as a function of altitude and detected other species in the atmosphere such as the chemically inert noble gases. A comparison of noble gas abundances on other planets and the sun will help distinguish between possible mechanisms of planetary formation and evolution of the atmosphere. Since Jupiter is the most massive planet in the solar system, the noble gas abundances found there are expected to closely reflect the abundances in the solar nebula from which the planets formed.

Atmospheric species with molecular weights from 2 to 150 Atomic Mass Units were analyzed and signals from more that 6000 values of mass to charge were taken during the descent. Preliminary findings [1] indicate that the abundance ratio of helium to hydrogen in the atmosphere is near but slightly lower than the solar value at 0.156 (by volume) while the abundance ratio of methane is higher, and the abundance ratio of water during the early part of the descent is surprisingly lower than those predicted using solar values of carbon and oxygen (i.e., a much dryer atmosphere than expected). However, hydrogen sulfide, water, and other condensable species show a substantial increase in mixing ratio at the highest pressures encountered during the descent. These observations coupled with the observation that the Probe entered Jupiter in a relatively cloud free region and in an infrared hot spot are presently stimulating a reevaluation of prior models and enabling a new understanding of the atmospheric circulation on Jupiter.

1. "The Galileo Probe Mass Spectrometer: Composition of Jupiter's Atmosphere," H. B. Niemann, S. K. Atreya, G. R. Carignan, T. M. Donahue, J. A. Haberman, D. N. Harpold, R. E. Hartle, D. M. Hunten, W. T. Kasprzak, P. R. Mahaffy, T. C. Owen, N. W. Spencer, and S. H. Way, *Science*, **272**, 846-849, 1996.

- Evolution of Water on Mars

In preparation for future Mars missions, analysis of the relation between the present Deuterium/Hydrogen (D/H) ratio and an early water reservoir on the planet was carried out to obtain insight on the liquid environment in which early life may have evolved. It was found that the winds in the upper atmosphere of Mars significantly enhance the Jeans escape flux of D and consequently increase previous estimates of the size of a juvenile water reservoir by factors of three or more [1]. The foundation for this work sprung from the analysis of measurements made of the D/H ratio in the atmosphere of Venus, which led to the identification of the dominant escape mechanism of these constituents and in turn to the conclusion that Venus had a significant reservoir of water more than four billion years ago, equivalent to a range of 125 to 570 m of liquid distributed uniformly on the surface [2].

1. "Effects of Wind-Enhanced Escape on the Evolution of Water on Mars," R. E. Hartle, *EOS Trans. AGU*, Fall Meet. Suppl., **77(46)**, F431, 1996.

2. "Hydrogen and Deuterium in the Thermosphere of Venus: Solar Cycle Variations and Escape," R. E. Hartle, T. M. Donahue, J. M. Grebowsky, and H. G. Mayr, *J. Geophys. Res.*, **101**, 4525, 1996.

Solar Effects

- Detection of Climatic Signals in Mesospheric Water Vapor

This study [1] explores the feasibility of identifying long-term changes in the mesospheric water vapor as a result of the increasing level of methane and the solar cycle modulation of Lyman □. A number of recent studies [2, 3] have suggested that changes in mesospheric water vapor and temperature may be good indicators of changes in carbon dioxide (CO_2) and methane (CH) concentrations on climatic time scales. Water vapor has no significant source in the mesosphere. It is

4
produced in the stratosphere by oxidation of methane and is transported into the mesosphere via winds and eddy transport where it is photo dissociated by Lyman α. Since methane is biologically produced and affected by human behavior, long-term changes in mesospheric water can be affected by the increasing level of methane on the surface of Earth due to anthropogenic activity. The variation in water vapor caused by the solar cycle has a modulating influence on the secular increase of water vapor in the mesosphere. The current study is based on recent measurements of water vapor in the mesosphere and the solar Lyman α flux from the UARS HALOE and Solar Stellar Irradiance Comparison Experiment (SOLSTICE) instruments during the declining phase of solar cycle 22 when solar activity decreased from a near maximum to a near minimum level. The analysis of these data sets, in conjunction with the Goddard two dimensional (latitude and altitude) chemistry and transport model, suggests that the methane-related increase in water vapor at mesopause heights (~80 km) may be of the order of only 2-3% in comparison to a modulation of about 30-40% caused by the solar cycle variation of Lyman α from 1991 to 1995. This relation changes dramatically with decreasing heights. In the lower mesosphere (60-65 km), the solar cycle related changes in water vapor are comparable to the predicted methane related change. The long term monitoring of the mesospheric water vapor may therefore offer an opportunity for detecting climatic signals in the atmosphere.

1. "The Seasonal and Long Term Changes in the Mesospheric Water," S. Chandra, C. H. Jackman, E. L. Fleming, and J. M. Russell III, *Geophys. Res. Lett.*, 1996.

2. "Global Change in the Mesosphere-Lower Thermosphere, Has it already Arrived?," G. E. Thomas, *J. Atmos. Terr. Phys.*, **58**, 1629-1656, 1996.

3. "Is the Polar Mesosphere the Miner's Canary of Global Change?," G. E. Thomas, *Adv. Space Res.*, **18(3)**, 149-158, 1996.

Climate Analysis

- New Insights into Mechanisms for SST-Convection Interaction over the Tropical Oceans

Using TOGA-COARE data, scientists in the Climate and Radiation Branch [1] have found that the warm pool SST and the overlying atmosphere undergo continuous cycles of alternate cold and warm states on time scales of one to two months. The warm pool region of the tropical western Pacific and Indian Ocean is the largest reservoir of heat and moisture in driving the global general circulation and the global water and energy cycles. This region also represents one of the most stable components of the Earth's climate system. It has been suggested that because of the huge heat capacity and the strong negative feedback processes within the warm pool ocean-atmosphere system, the warm pool may act as a flywheel to moderate major global warming events, delaying and even sequestering warming signals in the tropical ocean surface.

The cycles of cold and warm states found in the TOGA-COARE data occur as mutual dynamical and thermodynamical adjustments of SST and organized large scale convection [1]. This mutual adjustment represents one of the dominant modes of the warm pool-convection system interaction on seasonal to interannual time scales. It may also be responsible for the long-term stability of the warm pool SST. Results indicate that through the large scale teleconnection between the Indian Ocean and the western Pacific, convective growth and SST warming over the warm pool are self-limiting, with quasi-periodic cycles. An inverse relationship in the form of an oscillating dipole is found between convection over the Indian Ocean and the western Pacific. Coupling with SST appears to enhance the amplitude of the dipole.

1. "Mechanisms of Short-Term Sea Surface Temperature Regulation: Observations During TOGA-COARE," K.-M. Lau and C. H. Sui, in press *J. Climate*, 1996.

Aerosols

- A New Method for Detection of Absorbing Aerosols (Dust and Smoke) from TOMS Data

A newly developed TOMS algorithm obtains global distributions of UV-absorbing aerosols from measured 340 nm and 380 nm radiances [1, 2]. The data cover the period 1979 to 1993, and since July 1996 for the new ADEOS and Earth-Probe/TOMS. Time series for the major sources of biomass burning and desert dust show the frequency of occurrence over land and oceans. A key finding has been the identification of the major sources of most atmospheric dust. Sporadic sources of aerosols are also seen (volcanic ash and oil fires, e.g. Kuwait). Year-to-year variability of UV-absorbing aerosol amounts has been determined for the following major aerosol source regions: 1. Central South America (Brazil) near 10_S latitude, 2. Africa near 0_ - 20_S and 0_ to 10_N latitude, 3. Saharan and Desert and sub-Saharan region (Sahel), Arabian Peninsula, and the northern border region of India near 25_N latitude, 4. Indonesia, Eastern China and Indochina, and near the mouth of the Amazon River, due to agricultural burning, and 5. Northeastern China, due to coal burning and dust. The first three of these dominate the injection of UV-absorbing aerosols into the atmosphere each year and cover areas far outside their source regions. Much dust originates from agricultural regions, frequently within arid areas like the Sahel region of Africa and intermittently dry drainage areas and streams. In addition to the drought cycle, this suggests there may be an anthropogenic component to the amount of dust injected into the atmosphere each year.

1. "Detection of Biomass Burning Smoke from TOMS Measurements," N. C. Hsu, J. R. Herman, P. K. Bhartia, C. J. Seftor, O. Torres, A. M. Thompson, J. F. Gleason, T. F. Eck, and B. N. Holben, *Geophys. Res. Lett.*, **23**, 745-748, 1996.

2. "Global Distribution of UV- Absorbing Aerosols From Nimbus-7/TOMS Data," J. R. Herman, P. K. Bhartia, O. Torres, C. Hsu, C. Seftor, E. Celarier, accepted for publication, *J. Geophys. Res.*, 1996.

Validation Networks

- Critical Ocean Rainfall Observations for TRMM Validation

With the acquisition during 1995 of an excessed NOAA/National Science Foundation WSR-88D radar system, Goddard was able to substantially improve weather measurement data recorded from the Kwajalein Atoll/Marshall Islands location. A key feature of the installation was the provision for a suitable tower (~25 meters) to rise above nearby building and palm tree obstructions. An equally important factor in extending the range for radar precipitation estimates is the acquisition of calibration data from rain gauges. To accomplish this, arrangements were made with the Republic of the Marshall Islands to install and operate several additional gauges on a number of other atolls located out to a range of 150 km from the radar. The radar became operational by the end of May 1996. Most of the additional rain gauges have been installed and are operational. Kwajalein will now have the capability to supply the crucial data needed to both verify TRMM instrument algorithms with instantaneous measurements and validate longer term climatological averages over a critical ocean region.

Operational Satellites

- Geosynchronous Advanced Technology Environmental System (GATES)--A Geosynchronous Environmental Observatory

In 1996, GSFC took an initiative to study how modern space technology could be used to create an advanced imager in geosynchronous orbit that would be an observatory for both weather and climate in our hemisphere. The Laboratory for Atmospheres appointed the GOES project scientist, who took the opportunity to combine the requirements from NOAA's National Weather Service (NWS) for a high-performance imager together with NASA's MTPE specifications for MODIS. The resulting system design is called the GATES [1]. GATES is a very compact, visible-infrared radiometer on its own small satellite, capable of beaming full-disk multispectral data within minutes for realtime distribution of high-quality images to weather forecasters, to research scientists, and to the general public. The GATES concept is synergistic with the other weather- and climate-observing systems of the next century, particularly for monitoring clouds and the diurnal cycle between overpasses by the polar-orbiting satellites. GATES goals have been well-received by the head of the NWS, by the NASA Administrator, and by the MODIS science team. A GATES phase-A engineering review was held in 1996. Because GATES is designed to use off-the-shelf components, a flight unit could be built, launched and operated within 3 years of a Phase-B design, much faster than previous GOES satellite development.

1. "GATES, an Advanced Geosynchronous Imaging System,", D. Chesters and D. Jenstrom, SPIE Conf. "GOES-8 and Beyond", Denver CO, August 1996.

Rain Measurements from Space

- TRMM Passive Microwave Algorithm

An operational microwave rainfall algorithm has been developed based upon first principles. The Goddard Profiling Algorithm (GPROF) is a multi-channel, physically-based hydrometeor profiling algorithm developed for SSM/I, TRMM and EOS/AMSR. The algorithm retrieves rainfall and its associated hydrometeor structure based solely upon the physics of precipitation systems without requiring ground calibration data. GPROF begins by constructing large databases of cloud model derived profiles. Radiative transfer computations at cloud model resolution are performed for each sensor frequency. The resulting brightness temperatures (Tb) are then convolved to the observing resolution using appropriate antenna gain functions. Using a Bayesian inversion method (integral form of the minimum variance solution), a solution can be found that is the product of the probability that a certain profile occurs multiplied by the probability that the observed Tb corresponds to a particular profile. The formal solution to the above problem is presented in detail in [1]. Applications of GPROF to high resolution aircraft and SSM/I satellite data are extremely encouraging. Because of the physical basis, additional sensor information such as the TRMM radar can easily be incorporated [2]. The latent heating derived from the cloud model can also be treated like a retrievable geophysical parameter. This has led to encouraging results in which the latent heat in hurricane intensification was studied.

1. "A Simplified Scheme for Obtaining Precipitation and Vertical Hydrometeor Profiles from Passive Microwave Sensors," C. Kummerow, W. S. Olson, and L. Giglio, *IEEE Trans. Geosci. Remote Sensing*, **34**, 1213-1232, 1996.

2. "A Method of Combined Passive/Active Microwave Retrievals of Cloud and Precipitation Profiles," W. S. Olson, C. Kummerow, G. M. Heymsfield, I. J. Caylor and L. Giglio, *J. Appl. Meteor.*, **35**, 1763-1789, 1996.

Ozone Changes

- Recent Estimates of Changes in Atmospheric Ozone and Comparison with Models

Stratospheric ozone is affected by anthropogenically caused chlorine and bromine increases, solar cycle ultraviolet flux variations, and the changing sulfate aerosol abundance due to several volcanic eruptions. A study [1] was recently completed, which included all three of these variations, with a two-dimensional (latitude and altitude) atmospheric chemistry and transport computer model to predict ozone variations over the 1979 to 1994 period. The model captures much of the variability and downward trend in total ozone that was measured by TOMS instruments, on Nimbus 7 and on Meteor 3, over this time period.

The model simulations predict a decrease in total ozone of about 4% from 1979 to 1994 due to the chlorine and bromine increases. The changing sulfate aerosol abundances can also significantly affect total ozone with the Mt. Pinatubo eruption computed to cause a decrease in global ozone by about 3% in 1992. Solar ultraviolet flux variations cause increases and decreases in total ozone with computed changes of about 1% from solar maximum to minimum.

Model predictions for the future indicate that total ozone should start to recover from its lowest levels by the late 1990's. Future measurements of ozone are crucial to verify the recovery process.

1. "Past, Present, and Future Modeled Ozone Trends with Comparisons to Observed Trends," C. H. Jackman, E. L. Fleming, S. Chandra, D. B. Considine, and J. E. Rosenfield, *J. Geophys. Res.*, **101**, 28753-28767, 1996.

(Return to Table of Contents)

5.3 Modeling

Cloud and Mesoscale Modeling

- Mesoscale Modeling of Convective Systems and Their Associated Precipitation Processes

The GCE model has been used to quantitatively determine the effects of longwave radiation on squall lines, both tropical and midlatitude. The model results show that longwave radiation enhances precipitation, about 30 percent in the tropics and 8 percent at midlatitudes. The GCE simulations also indicated that the increase in relative humidity caused by longwave radiative cooling (no one has proposed this before) resulted in much more rainfall because of the high moisture contents in the Tropics. The midlatitude cloud system with a higher Convective Available Potential Energy (CAPE) and lower humidity environment was only slightly affected by longwave radiative processes. This strongly suggests that radiative processes could play a significant role in the daytime minimum/nighttime maximum precipitation cycle found over most oceans [1].

Additional GCE model results include the following: 1. latent heat flux from the ocean and subsidence induced by deep convection (not the convective downdrafts as suggested by theoretical studies) are the two major processes acting against each other that keep the CAPE in the tropics nearly constant; 2. higher CAPE is co-located with areas of higher equivalent potential temperature (caused by larger latent heat fluxes); 3. cloud updrafts are mainly initiated by dynamic forcing - strong convergence in the lower troposphere below the 1.5 km level. These results could be used to improve the representation of convective processes (i.e., the triggering function in cumulus parameterization schemes) in GCMs and climate models [2, 3].

1. "Mechanisms of Cloud-radiation Interaction in the Tropics and Midlatitudes," W.-K. Tao, S. Lang, J. Simpson, C.-H. Sui, B. Ferrier, and M.-D. Chou, *J. Atmos. Sci.*, 53, 2624-2651, 1996.

2. "The Impact of Ocean Surface Fluxes on a TOGA-COARE Convective System," Y. Wang, W.-K. Tao, and J. Simpson, *Mon. Wea. Rev.*, **124**, 2753-2763, 1996.

3. "Factors Responsible for Different Precipitation Efficiencies Between Midlatitude and Tropical Squall Simulations," B. S. Ferrier, J. Simpson, and W.-K. Tao, *Mon. Wea. Rev.*, 124, 2100-2125, 1996.

General Circulation Modeling

- Including Cloud Fractal Structure Improves Climate Simulations

Use of an "effective" cloud thickness which depends on the cloud fractal structure has been found to improve model simulations by the climate model of the ECMWF. The fractal structure of clouds helps explain how the liquid water content of clouds determines their albedo, which controls the amount of solar energy available to drive the Earth's climate system. Practical computing constraints require climate models to treat clouds as uniform. But uniform clouds are invariably too reflective, so that models must artificially reduce the cloud liquid water content, typically by a factor of three, in order to obtain a reasonable albedo. Recent work by scientists in the Climate and Radiation Branch has related the cloud liquid reduction factor to the fractal properties of clouds, through an "effective cloud thickness" [1, 2]. The model's absorbed solar radiation produces a more realistic climate simulation when observed fractal properties are used to compute cloud thicknesses. Fractal analysis is also being applied to clouds produced by high-resolution cloud resolving models in order to evaluate the realism of such model's convective parameterization schemes [3, 4]. If convective schemes can be found which produce realistic cloud fractal structures, which change appropriately when boundary conditions change, then global climate models might safely rely on cloud resolving models to determine changes in cloud albedo when the climate changes.

1. "Bounded Cascade Clouds: Albedo and Effective Thickness," R. F. Cahalan, *Nonlinear Proc. Geophys*, **1**, 156-167, 1994.

2. "The Albedo of Fractal Stratocumulus Clouds," R. F. Cahalan, *J. Atmos. Sci.*, **51**, 2434-2455, 1994.

3. "An Extension of Cloud-Radiation Parameterization in the ECMWF Model: The Representation of Subgrid-Scale Variations in Optical Depth," M. Tiedke, *Mon. Wea. Rev.*, **124**, 745-750, 1995.

4. "Fractality in Idealized Simulations of Large-Scale Tropical Cloud Systems," J.-I. Yano, J. C. McWilliams, and M. Moncrieff, *Mon. Wea. Rev.*, **124**, 838-848, 1996.

- New Prognostic Cloud Water Parameterization

The new cloud scheme called Microphysics of Cloud with Relaxed Arakawa-Schubert (RAS) cumulus parameterization (McRAS) has been completed and tested. McRAS is designed for simulating more realistic clouds and cloud-radiation interactions. It uses several new design concepts introduced in [1]. Its major novel features are prognostic clouds that advect in the horizontal and vertical directions and have a physically based cloud life-cycle. McRAS uses downdrafts [2];

full cloud-microphysics within convective towers and anvils; cloud-radiation interactions [3]; cloud microphysics [4, 5]; cloudiness inhomogeneity correction [6]; and several other tunable parameters from observations and sensitivity studies with the field data and/or GEOS-1 GCM.

McRAS features prognostic equations for the cloud water substance and cloud mass fraction. These equations are coupled to all the other prognostic equations of the GCM. In cumulus convection, RAS provides the mass flux. The new cloud-buoyancy equation (cloud-scale vertical momentum equation) yields fractional areas and ascent velocity of the cumulus mass flux. These form the key inputs for the cloud microphysics. Large-scale cloud parameterization is an integral part of the new cloud microphysics. The generation of large-scale (LS) clouds is linked to the growth of relative humidity above a threshold value (derived from observations). Boundary layer (BL) clouds are produced if supersaturation is reached within the BL eddies that rise toward the inversion layer. These clouds detrain beneath/into the inversion layer. For all clouds, the condensate-to-precipitation conversion is obtained from the growth of hydrometeors by accretion, collection, and Bergeron-Fiendsen processes. Clouds dissipate by entrainment of dry ambient air and/or drying through geophysical interactions and subsidence. The problem of advecting a discontinuous cloud-field is solved by appropriately combining diffusion and advection schemes.

McRAS has been tested with GATE, Atmosphere Radiation Measurement-Cloud and Radiation Testbed (ARM-CART), and TOGA-COARE datasets. It has shown promise in the 17-layer GOES-1 GCM that is being prepared for climate studies with an emphasis on more realistic cloud processes [7].

1. "A Cloud Microphysics Scheme with Relaxed Arakawa-Schubert Cumulus Parameterization (McRAS) for use in GCMs," Y. C. Sud and G. K. Walker, in preparation, 1997.

2. "A Rain-Evaporation and Downdraft Parameterization to Complement a Cumulus Updraft Scheme and its Evaluation Using GATE Data," Y. C. Sud and G. K. Walker, *Mon. Wea. Rev.*, **11**, 3019-3039, 1993.

3. "A Prognostic Cloud Water Parameterization for General Circulation Models," A. D. Del Genio. N.-S. Yao, W. Kovari, and K. K.-W. Lo, *J. Clim.*, **9**, 270-304, 1996.

4. "Parameterization of Condensation and Associated Clouds in Models for Weather Prediction and General Circulation Simulation," In: Physically Based Modelling and Simulation of Climate and Climatic Change, H. Sundqvist, ed M. E. Schlesinger, Riedel, Dordrecht, Part 1, 433-461, 1988.

5. "Representation of Clouds in Large Scale Models," M. Tiedtke, *Mon. Wea. Rev.*, **121**, 3040-3061, 1993.

6. "Bounded Cascade of Clouds: Albedo and Effective Thickness," R. Cahalan, *Non-Linear Processes in Geophysics*, **1**, 156-167, 1994.

7. Calibration and Validation of McRAS in the 17-Layer GEOS GCM," to be submitted to *J. Clim or J. Earth Inter.*, 1997.

(Return to Table of Contents)

(Go on to Section 6)

Send E-mail to the maintainer of this page.(rumburg@dao.gsfc.nasa.gov)
Responsible NASA official: Bob Theis